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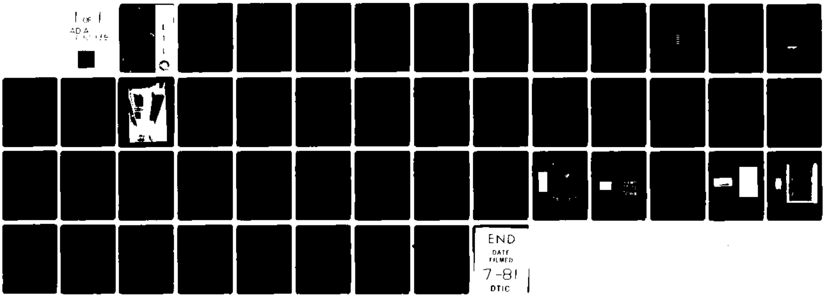

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A cartographic electron beam scanner design study

P. F. Grosso
A. A. Tarnowski

Image Graphics, Inc.
107 Ardmore Street
Fairfield, CT 06430

APRIL 1981

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The feasibility of adding a scanning/readout capability to Cartographic Electron Beam Recorder System was successfully demonstrated. An electron beam scanning mode of operation would allow cartographic line and gray shade data recorded on film to be rapidly digitized using a high resolution scanning electron beam. Further engineering programs are recommended to develope this capability.

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Preface

The work described in this report was authorized by the U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia, 22060 under Contract No. DAAK-70-79-C-0132 and was conducted by Image Graphics, Inc. (IGI) under the direction of Patrick F. Grosso with Andrew A. Tarnowski serving as the Project Manager.

The contract was performed under the technical direction of the Automated Cartography Branch, Mapping Developments Division, U.S. Army Topographic Laboratories (USAETL) under the direction of Howard Carr. Fred Merkel served as the Contracting Officer's Technical Representative. The following individuals at IGI made significant contributions to the success of this program.

Brian Anderson
John Breslawski
John Turek
Donald Walker

1.0 Introduction

The constantly increasing amount of data which is available to the cartographic community has created the need for automated systems for the production of various map products and for the rapid retrieval and manipulation of existing and new map data bases.

A Pre-Production Model Cartographic EBR System(1) developed by IGI for U.S.A.E.T.L. under Contract Number DAAK70-78-C-0188 was recently installed at the Defense Mapping Agency's Hydrographic/Topographic Center, Washington, D.C. This system is able to automatically plot and record a variety of map products and high resolution imagery on film.

This report describes the engineering program carried out at Image Graphics to investigate the possibility of adding an Electron Beam Scanner (EBS) mode of operation to the Pre-Production Model Cartographic EBR System. The electron beam scanner mode of operation allows cartographic line and gray shade data recorded on film to be rapidly accessed and digitized using a high resolution raster scanning electron beam. The film used for most of the scanner experiments was an electron sensitive film containing a scintillator layer which luminesces when scanned with electrons. The light output generated from the film is detected by a photomultiplier tube and transformed into an analog electrical signal. Data previously recorded as an image on the film cause variations in the intensity of the light reaching the photomultiplier thus modulating the generated electrical signal.

Analog signals produced in the EBS mode of operation of the Cartographic EBR System were displayed directly on a CRT storage display or sampled and quantized into discrete digital numbers which were used as computer input and transferred to magnetic tape or magnetic disk for storage and subsequent processing. The magnetic tapes thus produced were used to control image and data recording with the experimental Cartographic EBR System supplied as GFE to the program by U.S.A.E.T.L.

In addition to experiments with commercially available films, several luminescent materials were coated on images and graphics which had been previously recorded on conventional EBR films. These luminescent images were successfully scanned and re-recorded in the Cartographic EBR.

The demonstration of the feasibility of adding a scanning/readout capability to the Pre-Production Model Cartographic EBR System warrants further investigations of raster scanning of a variety of products such as map separations, graphics, line work, continuous tone imagery, digital data, etc. The possibility of vector scanning (line following) using a controlled electron beam, should also be investigated.

2.0 Technical Discussion

2.1 Electron Beam Scanner

Black and white line or graphics data and continuous tone (gray shade) imagery were recorded and read out by electron beam scanning techniques using the Experimental Model Cartographic EBR System supplied as government furnished equipment (GFE) by U.S.A.E.T.L.[6]

Initially a design study and an experimental investigation were conducted using available Eastman Kodak SO-214 Scintillator Film and Eastman Kodak SO-219 Film coated with available liquid scintillators. A cross section of the SO214 film is shown in Figure 1. The film consists of an Estar base and three coatings: (a) a conductive coating to remove electrical charges during recording; (b) a silver halide emulsion for recording latent images; and (c) a plastic scintillator coating which luminesces under electron bombardment. After recording a latent image in the EBR, the film is processed in the usual manner to produce a visible image. Interraction of the electron beam and the scintillator coating on processed film produces photons which are transmitted through the film and collected with a photomultiplier tube. The electrical output of the photomultiplier tube is amplified and converted into digital scan data.

The SO-214 Scintillator film has a very high resolution capability, (in excess of 1000 cycles per mm) and is especially prepared by Kodak for direct electron exposure and electron beam readout. It is a direct-reversal film with a wide dynamic range which may be processed in standard developer and fixer. The film can be also processed in commercially available automatic processing equipment.

The scintillator coating glows when struck by electrons similiarly to a phosphor; it has no grain and a very fast light output decay. The fast light output decay enables readout of data at very high frequencies (100-200 MHz has been demonstrated by Ampex Corporation). Unlike a phosphor a scintillator also provides signal amplification since each electron striking the scintillator produces about 10 photons of emitted light energy.

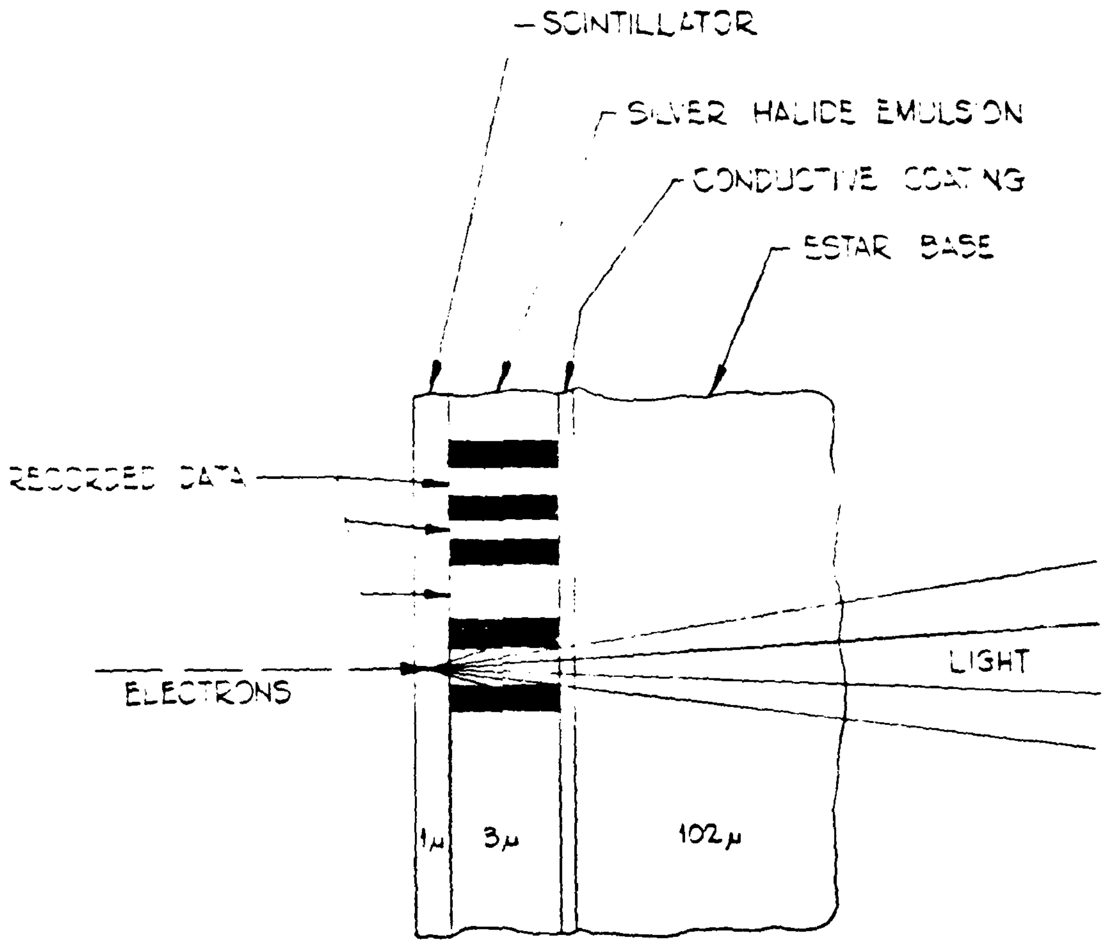

Figure 1 - Scintillator Film Cross Section

2.2 Data Retrieval Process

Scintillator film chips with visible line work, graphics data or gray shade imagery were placed in a film holder and mounted in the Cartographic EBR film chamber. The Cartographic EBR was operated in a raster scanning mode. The electron beam scans the scintillator film chip at constant beam current as shown in Figure 2. Wherever the scanning electron beam strikes the scintillator coating light is emitted. The opaque images areas modulate the light intensity by preventing light from transmitting through the film to a photomultiplier tube. The photomultiplier tube collects the emitted light, converting the recorded information into an electrical signal.

The EBR scintillator readout process is 40 to 50 times more efficient than conventional flying spot scanner techniques, because of the higher quantum efficiency of scintillators and because no optical lenses are required. Whenever photons strike the surface of the photocathode of the photomultiplier tube (PMT), they are converted into electrons whose electrical signal is amplified by the dynode section of the PMT. The pulsed output signal of the PMT is processed by a signal processor and passed into a register of an analog-to-digital converter which produces a continuous string of digitally coded numbers corresponding to a continuous sequence of samples. The processed analog signal may be displayed on a CRT Storage Display during the scanning process.

Black and white data on film modulate the video data on-off similiarly to binary serial data. Once the analog signal has been converted into binary, bit stream, digital data, it is passed into the memory of the PDP11/34 minicomputer controller using the raster scan direct memory access (DMA) channel as shown in Figure 3. The DMA automatically updates the memory after passing each block of 16 Bit words. The memory stores one complete line of scanned data (i.e. 10,000 Bytes) and transfer the data at a rate of 1 word (2 Bytes) at a time into the PDP11/34 minicomputer. The mini-computer controller transfers 1 a byte at a time to the 9 track magnetic tape recorder, which records the digital data at a density of 800 bits per inch at a rate of 45 inches per sec.

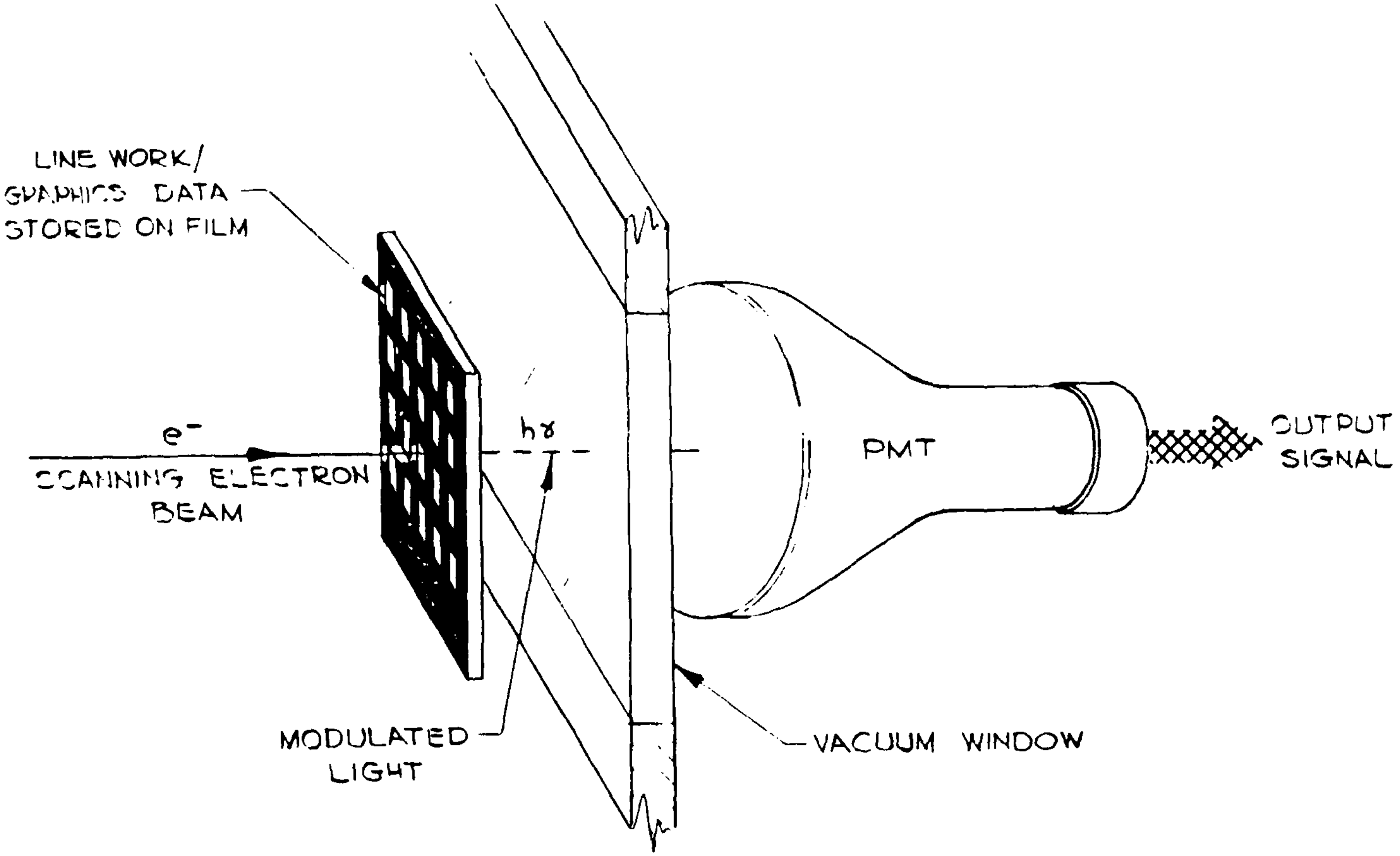

Figure 2 Readout Process

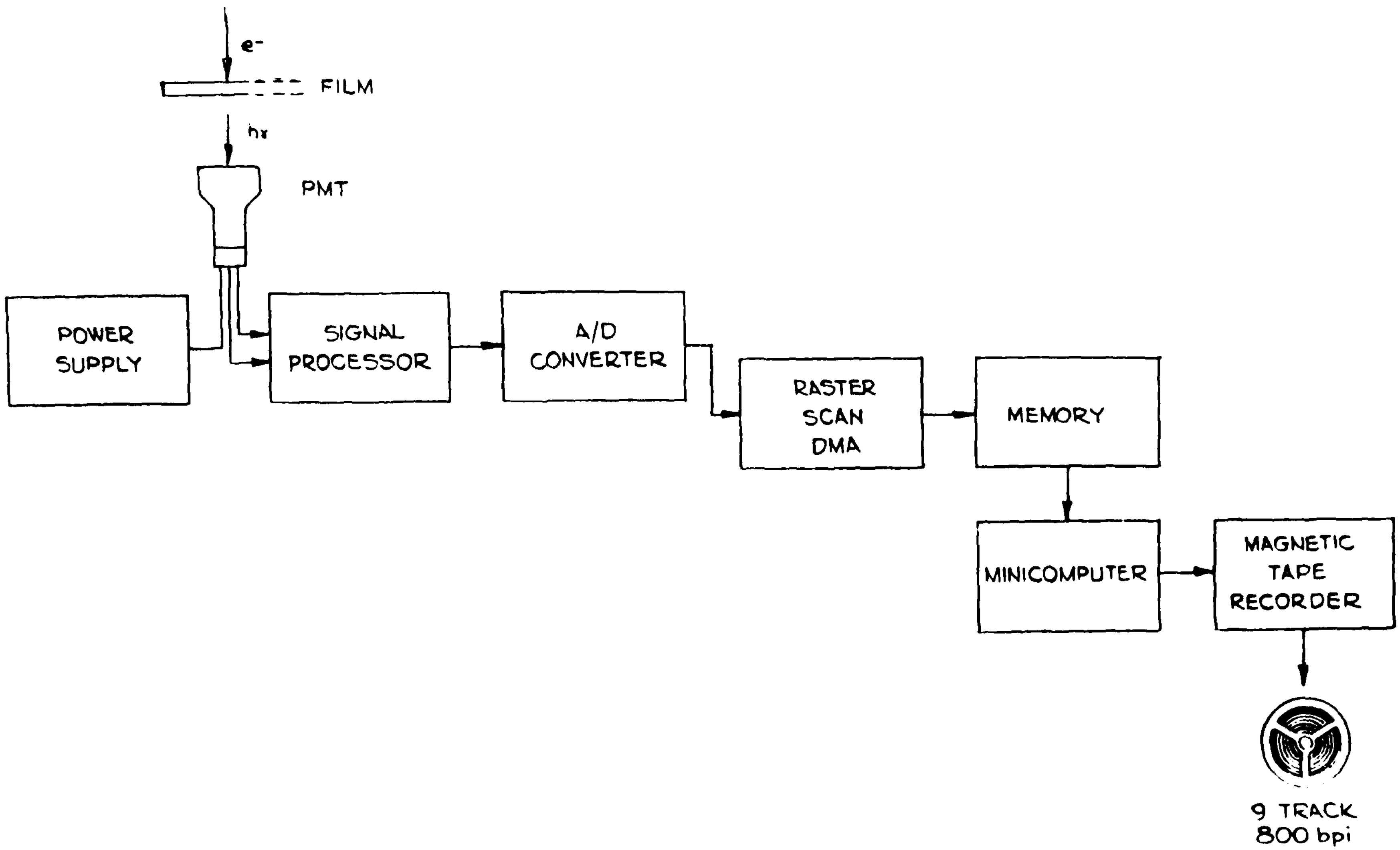

Figure 3 Block Diagram of Readout

The raw digital data derived in the scanning process is in the correct format of a plot tape required to drive the Cartographic EBR system in a raster recording mode. Experiments indicate that the raw digital data does not require further computer processing before it can be used to control subsequent electron beam recording of the line work or graphics data.

2.3 Description of Experimental Model Cartographic EBR System

The experimental model Cartographic EBR System, supplied as GFE by USAETL and shown in Figure 4, is a stand-alone, high performance electronic recording system which is capable of precision plotting (recording) high resolution imagery on various electron sensitive media. It is ideally suited for the automated production of computer generated maps; recording of high resolution sensor imagery; and numerous other high quality micrographics applications.

The Cartographic EBR System has several modes of operation which allow it to be used for the automated production of a variety of existing and new map and image products such as:

Minimap color separations

Continuous tone imagery from satellite and aerial reconnaissance sensors data

Radar imagery

Flight Information Publications (FLIP) Charts and Texts as back-up for DMAAC AAIPS Program

Computer generated micrographics (including symbols and characters of graphic arts quality)

Binary raster data

Run-length encoded raster data

High Resolution image processing and enhancement

2.3.1 Modifications to the Experimental Cartographic EBR System

In order to conduct an experimental investigation and demonstrate the feasibility of providing an electron beam scanner mode of operation for the 6.4 Pre-Production Model Cartographic EBR System, the .3 Experimental Model Cartographic EBR System required certain modifications:

Figure 4 Experimental Cartographic EBR System With Photomultiplier Tube Readout Station

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(a) a film holder was designed, fabricated and installed in the EBR.

(b) A photomultiplier readout station with amplifier and power supplies was assembled and installed in the EBR System as shown in Figure 4, at no cost to the program.

(c) an analog signal processor for encoding data and imagery scanned by the electron beam was designed, fabricated and installed in the Raster Scan Translator (RST) of the cartographic EBR System.

(d) a PDP 11/34 minicomputer controller with 128K MOS Memory, an additional RK05 Magnetic Disk Drive with 1.2 M Word storage capacity, a LA36 Terminal and a floating point processor and suitable interfaces were installed in the experimental Cartographic EBR System to provide complete compatibility with the software and hardware developed for the Pre-Production Model Cartographic EBR System installed at the Hydrographic/Topographic Center.

2.3.2 Modes of Operation

The experimental Cartographic EBR System is designed to operate in any one or combinations of the following ways to produce maps or pictures of various sizes and formats up to a maximum of 8¼ x 5 inches.

Vector

The Vector Mode controlled by the Symbol/Vector Generator (SVG) is used for plotting lines, grids, contours, rivers, streams, roads, stroke characters, etc. Vectors can be generated either incrementally (adjacent points in any one of 8 directions) or as stroke vectors, having a maximum length of 1024 address points.

Line widths are selectable from 6 microns to 261 microns with 6 bit (64 levels) control in 4 micron increments. Greater line widths can be achieved by juxtapositioning line segments.

Symbol

The Symbol Mode also controlled by the SVG, is used to compose and record graphic arts quality symbols for names sheets, text or symbology using a randomly positioned subraster. Character or symbol sizes can be varied from 8 to 250 mil inches and rotated in 1^{o} increments to follow "serpentine" features of a map or chart.

Recording rates for characters or symbols vary from 20 to 1000 characters per second, depending upon style, size and quality.

Raster

The Raster Mode controlled by the Raster Scan Translator (RST), is used to record raster scan data or sensor imagery using either digital or analog rasters. The digital raster data may be incrementally recorded point by point or run length encoded for data compression and higher throughput rates.

Raster configuration is extremely flexible and may be varied upon computer command from 500 - 32000 elements per scan and from 500 to 32000 lines per raster.

The analog raster generates scan rates which are continuously variable from 10 to 2000 scans per sec. Image recording time is dependent upon scan rate selected, image format, input data, and magnetic tape drive speed.

The digital Raster Mode of the RST was adapted for scanning for this program.

In addition, the RST has an internal Diagnostic Mode of Operation to record calibration test patterns that can be used to measure resolution, density range, transfer characteristics and geometric fidelity of the EBR.

2.3.3 System Configuration

The Cartographic EBR System is normally operated as an off-line stand-alone system using digital data from magnetic tape as an input. However, the EBR may also be used on-line with computers or sensors if suitable interfaces are provided.

The basic configuration of the Cartographic EBR System is shown in Figure 5. It consists of six functional sections:

1. Input Section
2. Control Section
3. Mass Data Storage
4. Data Translator
5. Recorder Unit
6. Operating Software Package

2.3.3.1 Input Section

The Input Section to the Cartographic EBR consists of one 9 track and one 7 track magnetic tape systems, which accept industry standard 1/2" magnetic tape with data densities of 800 bpi and operates at 45 ips. a Decwriter II keyboard console and a Tektronix 4014-1 keyboard console. The input system stored as data files control the flow of data to the CPU needed to generate each of the Cartographic products or high resolution imagery. The Decwriter and the Tektronix 4014-1 are used as auxiliary input/output (I/O) communications links with the CPU.

For names or symbol placement, the input commands call out the type of character style or special symbols which are stored on-line on a magnetic disk as digital representations and commands to the CPU to transfer the characters or symbols into computer memory. The input tape also provides recording parameters such as size, angle and position for controlling the Symbol/ Vector Generator.

For plotting lines, arcs and contours of variable widths, the input data files supply command codes to the minicomputer and Symbol/Vector Generator for computing position of the electron beam and variations in angle and line width.

For high resolution imagery or raster data, the input data files are supplied as an 8 Bit code to the minicomputer for controlling the Raster Scan Translator. The raster data may be binary or run length encoded for recording either black and white or grey level data.

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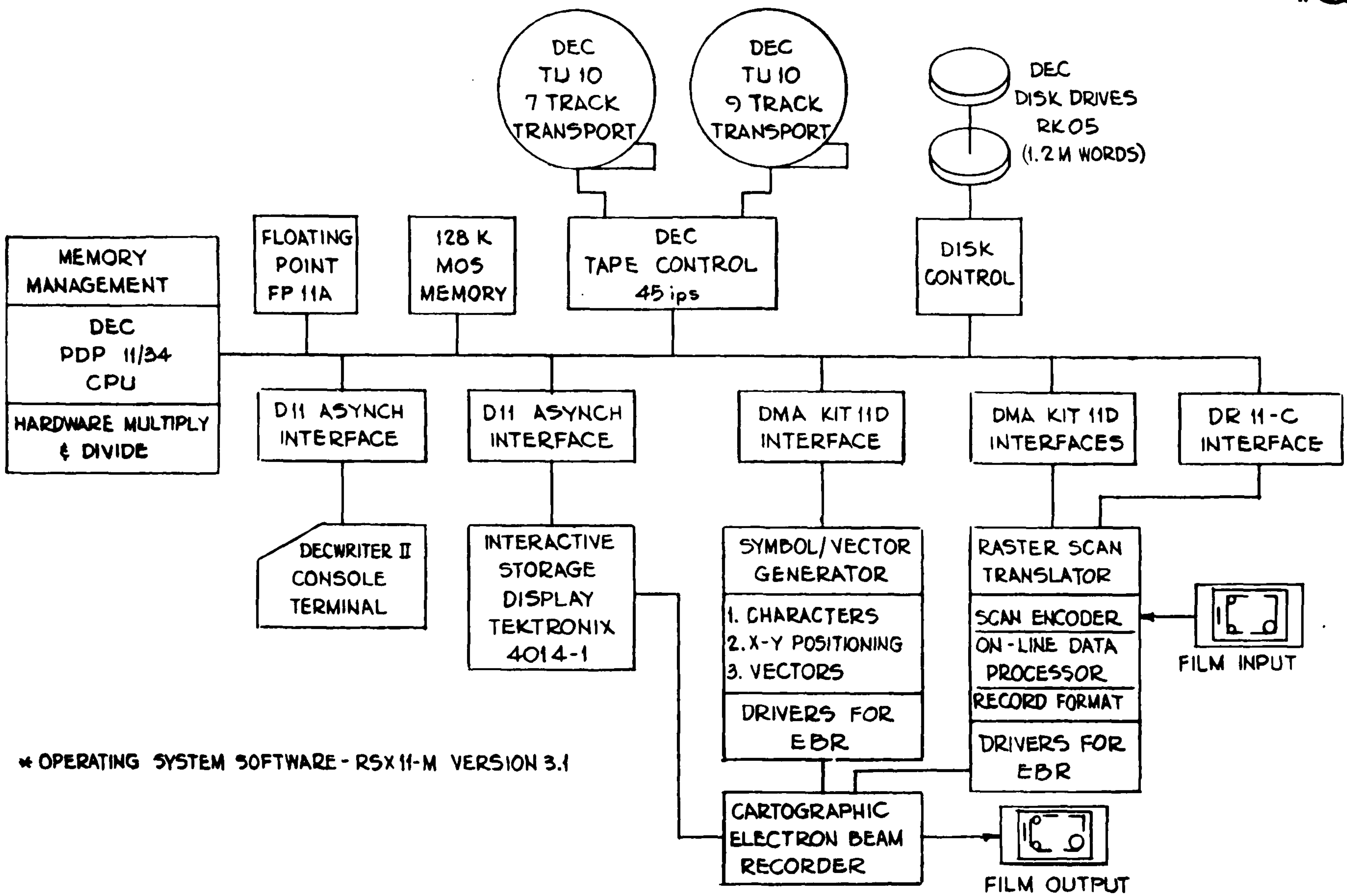

* OPERATING SYSTEM SOFTWARE - RSX 11-M VERSION 3.1

Figure 5 Experimental Model Catographic EBR System Block Diagram

2.3.3.2 Control Section

The Control Section consists of a Digital Equipment Corporation (DEC) PDP 11/34 minicomputer which is a basic binary processor with 128K words of memory. The CPU combines operating data and plotting instructions to the data translator to generate and position symbols, vectors, point plots or continuous tone data.

The CPU controls the digital data which is then converted into analog signals which in turn precisely control the electron beam.

2.3.3.3 Computer Controller Architecture

The computer controller used with the Cartographic EBR is shown in Figure 5. The Central Processing Unit (CPU) is a Digital Equipment Corporation (DEC) PDP 11/34 with an RSX 11M Version 3.1, disk operating software system. This hardware/software combination enables maximum flexibility and growth potential, high speed, multifunction operation, future program development and compatibility with existing software being developed by U.S.A.E.T.L., DMA and CIA. All RSX 11M utilities and options, including DECNET 11 network support, can be added without modifying the EBR System.

Direct Memory Access (DMA) channels interface the EBR via the Symbol/Vector Generator (SVG) and the Raster Scan Translator (RST) to the PDP 11. These DMA interfaces have their own drivers and can be treated as standard RSX peripherals such as disk or magnetic tape units.

The Computer Controller for the EBR is assembled in four cabinets consisting of the following:

PDP 11/34 Central Processor Unit

128K Words Parity MOS Memory

Battery Back-up

Programmer Console

Automatic Power Fail Detection/Restart Capability

4 Level Automatic Interrupt

Line Frequency Clock

Multi Device (Auto Bootstrap Loader)

Extended Instruction Set (Hardware Multiple and Divide)

Memory Management

DL11-C Current Loop (2-MA) Serial Line Interface

Kit 11 D Direct Memory Access Interfaces (3)

DL 11W Asynchronous Interface (300 baud line)

DR 11C 16 bit parallel interface

RK11 Disk Drive Control including two RK05, 1.2M word disk drives

Peripheral Mounting Panel

Tape Control with one 9 track and one 7 track 800 48 ips, tape transports.

LA 36 Decwriter II Console Terminal

The Tektronix Interactive Storage Display, (Model 4014-1) with Enhanced Graphics Option, which is also provided, may be operated in two modes: (1) via an analog adapter to the EBR, thereby displaying the recording in process or previewing scan data on magnetic tape at lower resolution and (2) through an asynchronous interface to the CPU.

2.3.3.4 Mass Data Storage

Two DEC 1.2 million word disks have been provided for storage of operating programs and of digitized representations of type fonts and symbols. One disk can be used as an on-line library for fonts.

Additional disks (up to 8) can be added to the controller to expand storage capacity for additional software programs or Font Libraries.

2.3.4 Data Translators

The Data Translator Circuits of the Cartographic EBR are contained in the Symbol/Vector Generator (SVG), the Raster Scan Translator (RST) with the On-Line Data Processor (OLDP) and scan options. The SVG and the RST convert digital data into analog signals which drive the EBR and the Tektronix storage display during the scanning or recording processes.

2.3.4.1 Symbol/Vector Generator (SVG)

The SVG consists of the following:

Incremental Point Plot Generator

Stroke Vector Generator with Intensity Control

Character Generator

Random Access Positioning Unit

Output signals to the Tektronix Storage Display Controls

The Symbol/Vector Generator, IGI SVG Model 100A, is a single unit which contains the X-Y positioning, character generation and stroke vector generation functions as shown in Figure 6.

The X-Y Positioning Subassembly provides absolute X-Y positioning over the entire EBR format with 32K addressability. The use of a 2^{18} internal addressability ensures that positioning errors levels become insignificant. The X-Y Positioning DAC's provide major beam positioning voltages or start addresses for all character or vector operations and are updated with absolute character right bearing (width) or vector end point coordinates after each operation to insure that errors will not be accumulated.

Line width control from 6 to 261 microns has been provided using either spot wobble or by repeating line segments. Line widths up to 250 mil-inches, may be achieved by repeating line segments.

The Character Generator has the ability to provide Graphic Arts quality characters in sizes of .008" - .256" at EBR scale. Characters are rotatable to a full 360 degrees in 1^{o} increments. The number of allowable cuts per scan line is limited to 108 or 216 depending on whether a low or high resolution font is specified. The area scan writing rates and wobble frequency are kept constant to maintain correct density for different character sizes and line weights. An intensity command in the software has been provided for control of intensity.

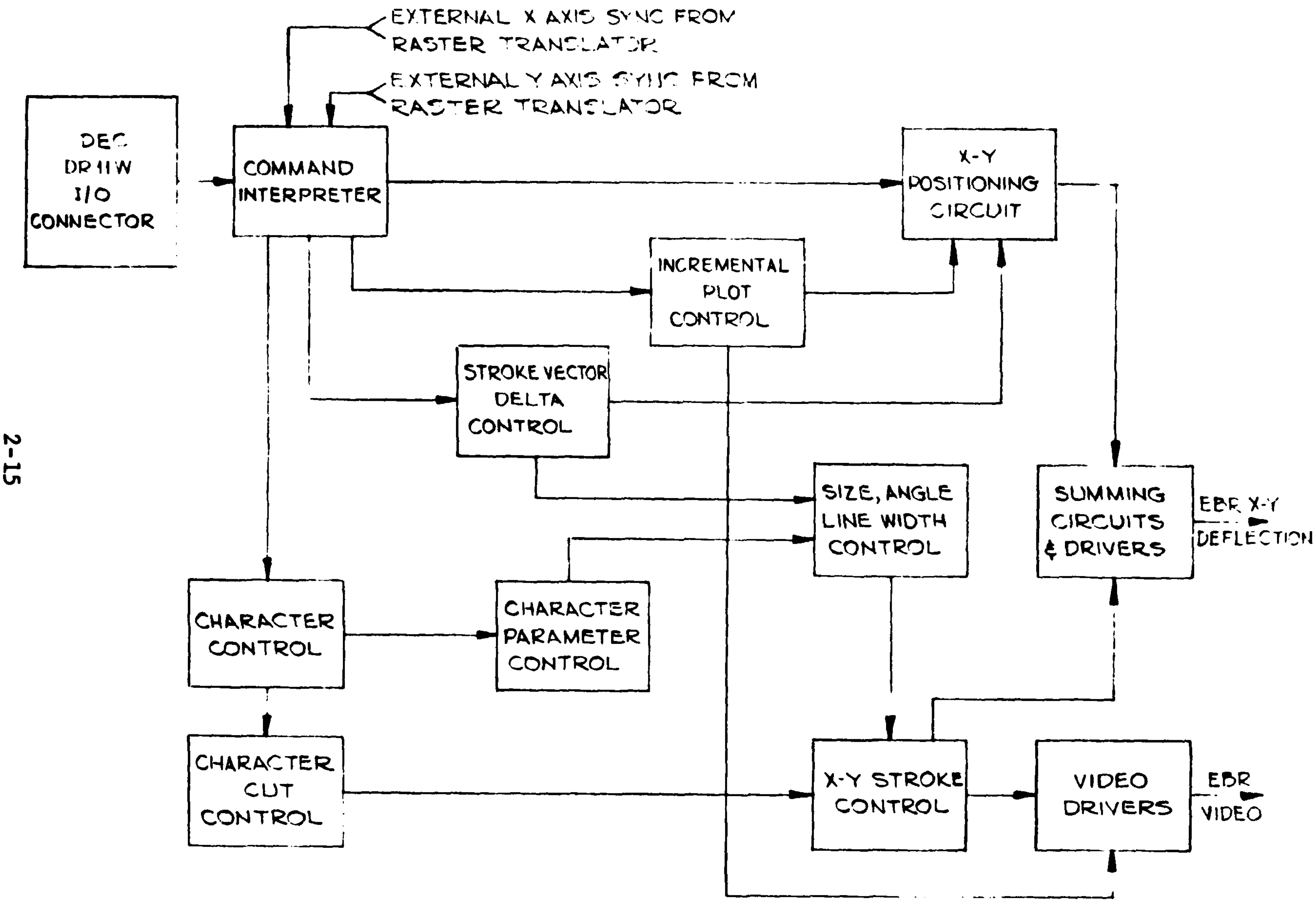

FIGURE 6 SYMBOL/VECTOR GENERATOR (SVG) BLOCK DIAGRAM

The two word end point format for the SVG stroke vector is both efficient and easy to program for long vectors, but is inefficient as the length of the vector stroke decreases, because 70 uSEC is required for calculating and positioning random vectors regardless of length. Since cartographic material contains numerous small vectors such as those found in curves, the SVG also accepts an 8 bit Incremental Vector Plot (IVP) format. Two computer words (16 bits per word) can command the SVG to write one stroke vector or four IVP vectors.

The stroke vector generator generates the base line of symbols produced by the character generator to allow even greater accuracy in character rotation and improved rotation accuracy to less than 1°.

The logic section of the SVG consists of three removable 16" x 7½" wire wrap circuit boards: Board 1 the digital control section; Board 2 a hybrid digital/analog section for character processing and major position deflection and Board 3 a hybrid digital/analog section containing the stroke vector generator, character sub-raster generator and sin/cosine generators. The logic boards are mounted on slides and hinges for easy access for servicing. All connections to boards are through plugs or connectors, thereby, allowing fast replacement. The top and sides of the logic box are removable when the box is withdrawn on slides from the standard cabinet.

Included in the SVG enclosure is a regulated power supply which provides +15V @ 2A, -15V @ 2A and -5V @ 17A. Power input to the SVG is a standard 120V, 60 Hz line cord equipped with a circuit breaker. Signal inputs to the SVG controller are through two 40 pin flat cable connectors on a rear connector panel. Signal outputs of the SVG are through 3 triax and one multi-conductor cable connectors on the rear connector panel.

The SVG Controller interface for the PDP 11/34 mounts in one system unit and requires system power of +5 volts $\pm 5\%$, 3 Amps. All I/O cables for interfacing to the SVG, unibus connector module (for interface to PDP 11 unibus) are provided with the SVG Controller.

2.3.4.2 Raster Scan Translator

The Raster Scan Translator (RST) hardware and software provided with the Cartographic EBR has 32K byte storage capacity which allows both digital and 32K byte storage capacity which allows both digital and analog raster imagery and data to be scanned or recorded. A block diagram of the RST and the Scan encoder section added to the RST is given in Figure 7.

Scanner and Recorder data may be organized in one of the following manners:

a. Binary continuous tone grey scale
b. Run length encoded continuous tone grey scale
c. Sequential binary black & white, or
d. Run length encoded black & white.

Data for digital raster mode is organized as either binary (black & white or grey scale) or run length encoded black and white.

Data for the analog raster is recorded a line at a time, as continuous tone grey scale or black and white. Continuously variable scan rates, which cover the range of less than 10 cycles/sec to 2,000 cycles/sec (100 msec. to 0.5 msec. per line) have been provided for the analog raster.

The CPU controls the digital data which is then converted to analog signals which control the precision electron beam over the film format. Corrective signals for linearity, geometry and astigmatism may be introduced during recording.

A video processor which includes a Gamma Amplifier is supplied for the Raster Operating Mode. The Gamma Amplifier may be used for enhancement of continuous tone imagery by varying the gamma transfer characteristic of the video signal from 1/2 to 2.

2.3.4.3 RST Scanning Process

The RST was originally designed to record data in a raster format. The scanner capability added to the RST is shown in Figure 8.(RST SCAN VIDEO ENCODER)

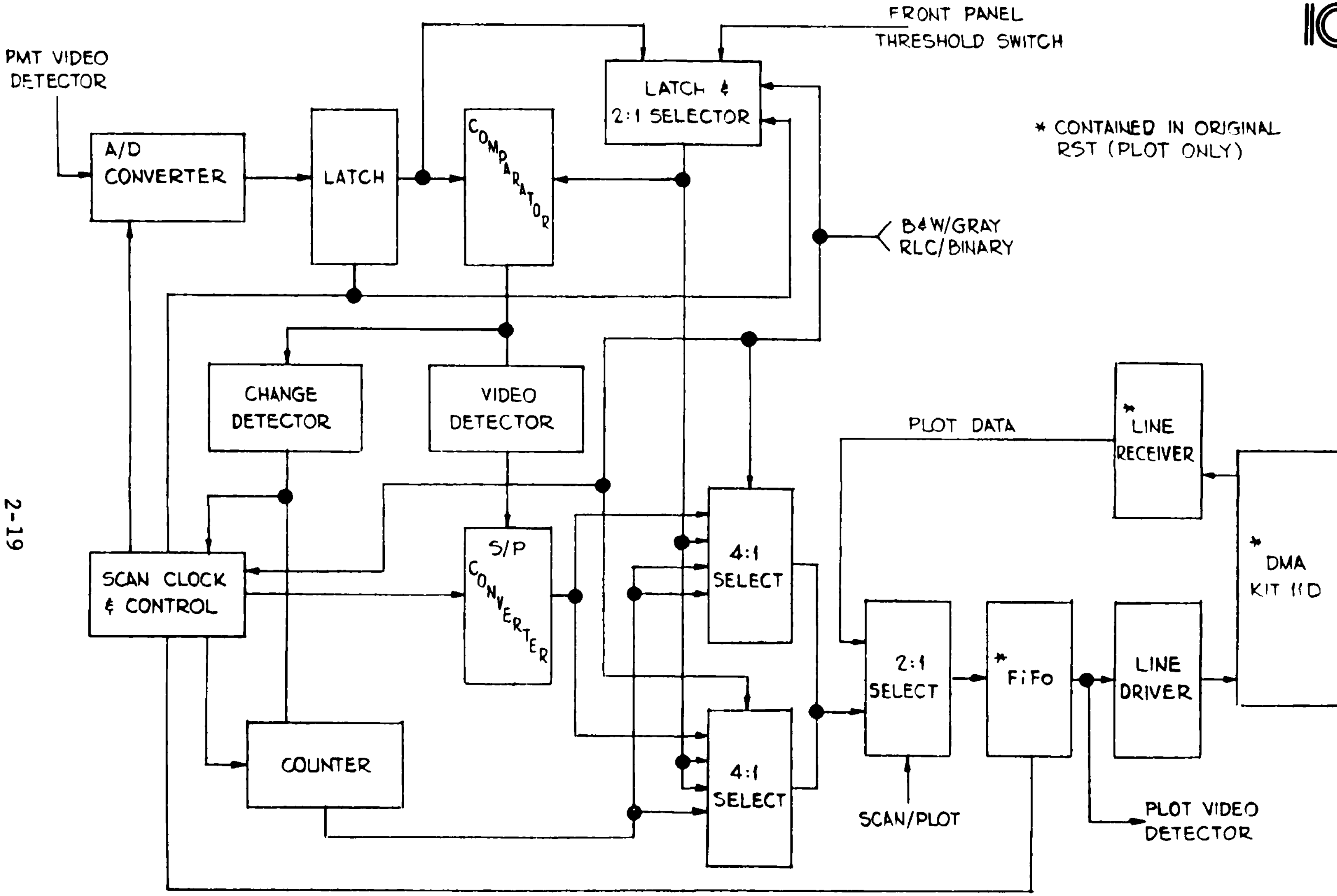

Figure 8 RST Scan Video Encoder Block Diagram

With the added logic shown in the block diagram, the RST has the ability to accept scanned data, digitize it, encode it into any of the various formats used for plotting, and transmit it to a computer via a DMA device for recording on magnetic tape. The tape can then be immediately played back and the scanned data recorded on film or presented on a monitor display with additional processing of the data required.

The video digitizing and encoding process is described in the block diagram of Figure 8. Initially analog scan data is received and digitized by an 8 bit A/D Converter. The output of the Converter, which is operating at the system data element rate, is placed in a one byte (8 bits) buffer Latch. The data is then compared either with a value preselected by a front panel threshold switch in the black and white mode or with the previous data byte in the gray shade mode. A mode switch determines which signals are to be compared and selects the correct one by means of a 2:1 Selector Latch circuit.

In the black and white binary mode, the Comparator output is encoded into the appropriate one's and zero's data sequence by a Video Detector and fed to a Serial to Parallel Converter circuit. The Converter is unloaded every 8 data elements and data sent a byte at a time through a 4:1 Selector circuit to a 128 word (16 bit word) FIFO (first in-first out) buffer and eventually to the computer via a DMA interface for recording on magnetic tape.

When operating in the black and white run-length-code (RLC) mode, the Comparator output is monitored by a Change Detector circuit. As long as the data output remains constant (i.e. all zero's or all one's), a Counter is incremented at the data element rate. Whenever a change in the data stream is detected, the value in the Counter (up to a maximum of 7 bits or 127) is transferred through the 4:1 Selector along with a video bit to the FIFO. The video bit and the 7 bit count form a data byte. The Counter is reset to zero each time a change occurs or each time it reaches its maximum count at which point a data byte is generated and encoded into the proper format.

Each data element in the gray level binary mode is digitized into one of 256 gray levels and is represented by one 8 bit byte. In this case, the digitized data is sent directly from the output of the 2:1 Selector Latch circuit through the 4:1 Selector to the FIFO and ultimately to the computer and magnetic tape. Since each data element requires a complete byte to describe its gray level value, this mode must operate at the maximum clock rate (i.e. data must be transmitted to the computer at one-half the data element rate, one-half since a computer word consists of two 8-bit bytes) and will produce the maximum amount of data since no data compression is achieved.

The fourth format mode which is gray level run-length-code performs in a manner similar to the black and white RLC mode. However, in this mode, the 8-bit data byte is separated into two 4-bit pieces. The high order 4 bits represent one of 16 possible gray levels. This data is taken by the 4:1 Selector from the 4 high order bits of the 8 bits representing the possible 256 gray levels of the video element. The low order 4 bits of the data byte are taken by the 4:1 Selector from the run-length counter and can account for a maximum run of 15 elements.

Once the data has been correctly formatted, operation is the same in all modes. The proper format is chosen by means of the 4:1 Selector and sent to a 2:1 Selector which allows either plot or scan data to be loaded into the FIFO buffer depending on the desired system function. After the scan data is loaded into the FIFO, it is transmitted by means of line drivers through a DMA device (in this case a DEC KIT 11-D) to the computer and finally recorded on magnetic tape.

2.3.4.4 Data Retrieval Process

The Scintillator film used for this experimentation (Kodak SO214) can be exposed and developed in a manner similar to that of films typically used in an EBR system. Other than a need for higher beam current and a different processing chemistry, plotting procedures are almost identical.

Once an image has been recorded and developed on scintillator film, it can be scanned in the EBR using the test set-up shown in Figure 9. A scintillator film chip with a visible developed image (which may consist of black and white or gray level data) is placed in a film holder and mounted in the Cartographic EBR Chamber. Since the only SO214 Scintillator film available for this project was 35 mm (1 3/8 inches) wide, a special holder had to be fabricated. The holder was made of 1/8 inch thick aluminum with a cutout, approximately 1 inch by 1 3/4 inch in the center of the plate for a film chip. When scanning or recording, the film chip is taped over the cutout in the plate and the holder is then placed in the EBR vacuum chamber and firmly fastened to the structure. Conductive tape is used to prevent any charge build-up on the film which can produce spurious deviations of the electron beam. Aluminum was used for the holder because it is non-magnetic; magnetic materials can also cause spurious deviations of the electron beam.

The EBR is operated in the raster scanning mode using the Raster Scan Translator (RST). The electron beam of the EBR, as controlled by the RST, scans the scintillator film chip at a constant beam current. Wherever the scanning electron beam strikes the scintillator coating on the film light is emitted. At any point where image data is present, the light intensity will be attenuated (to a degree dependent on the film density) before it is transmitted through the film to a pick-up photomultiplier tube (PMT). The PMT collects the transmitted light on a photosensitive surface and converts it into an analog electrical signal whose amplitude depends on the density level of data recorded on the scintillator film.

A specification sheet for the PMT (an SRC model 52B01) is given in Appendix A. This PMT is a standard off-the-shelf unit with a 2 inch face. A connection diagram for the PMT is shown in Figure 10.

The scintillator readout is 40-50 times more efficient than conventional flying spot scanner techniques. When photons strike the surface of the photocathode of the PMT, they are converted into electrons whose electrical signal is amplified by the dynode section of the PMT (Figure 10). The output of the PMT, which is now an electrical analog representation of the scanned image, is processed by a Tektronix type AM 502 differential amplifier to obtain the proper levels for the RST input section.

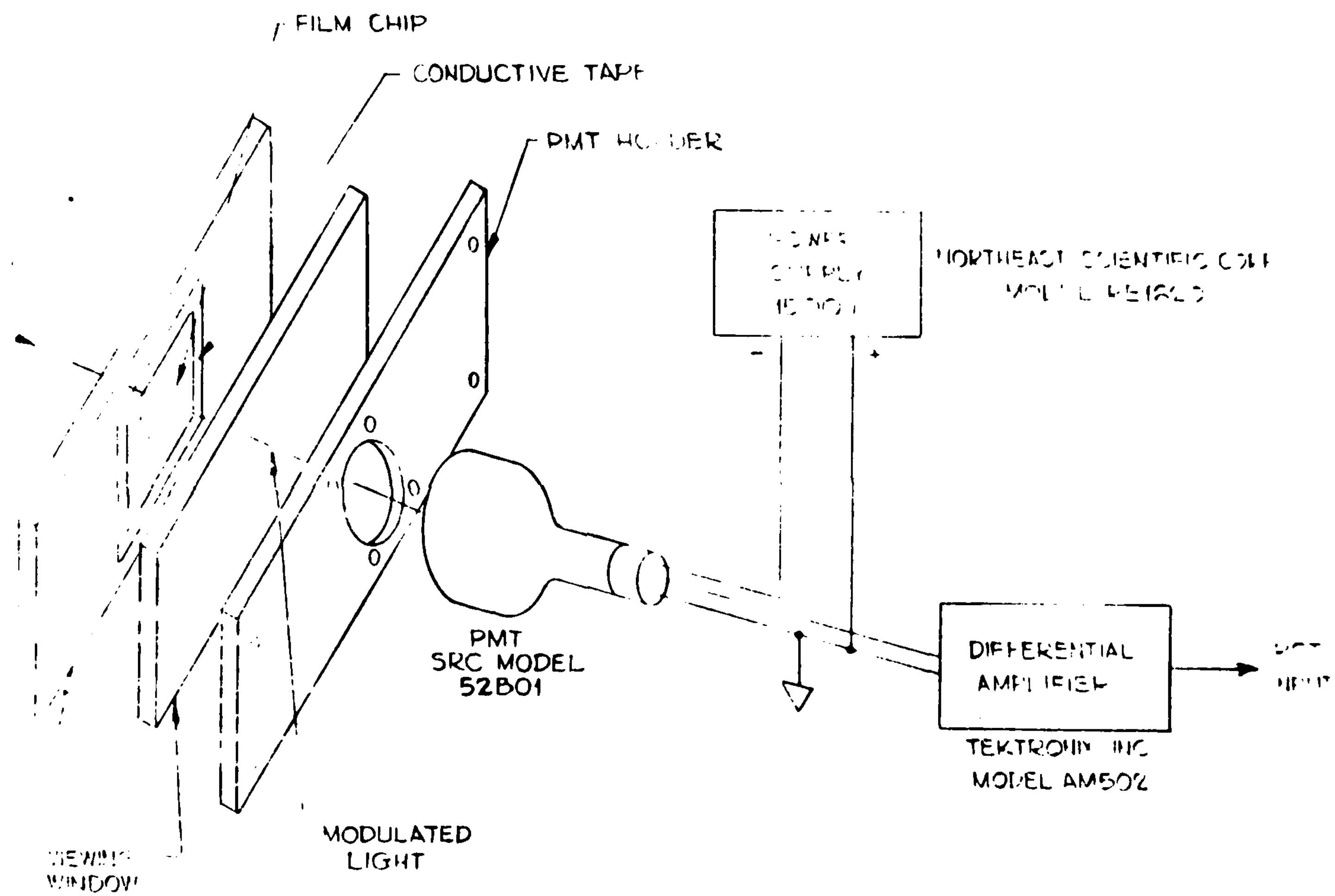

Figure 9 Scan Experiment Test Set-Up

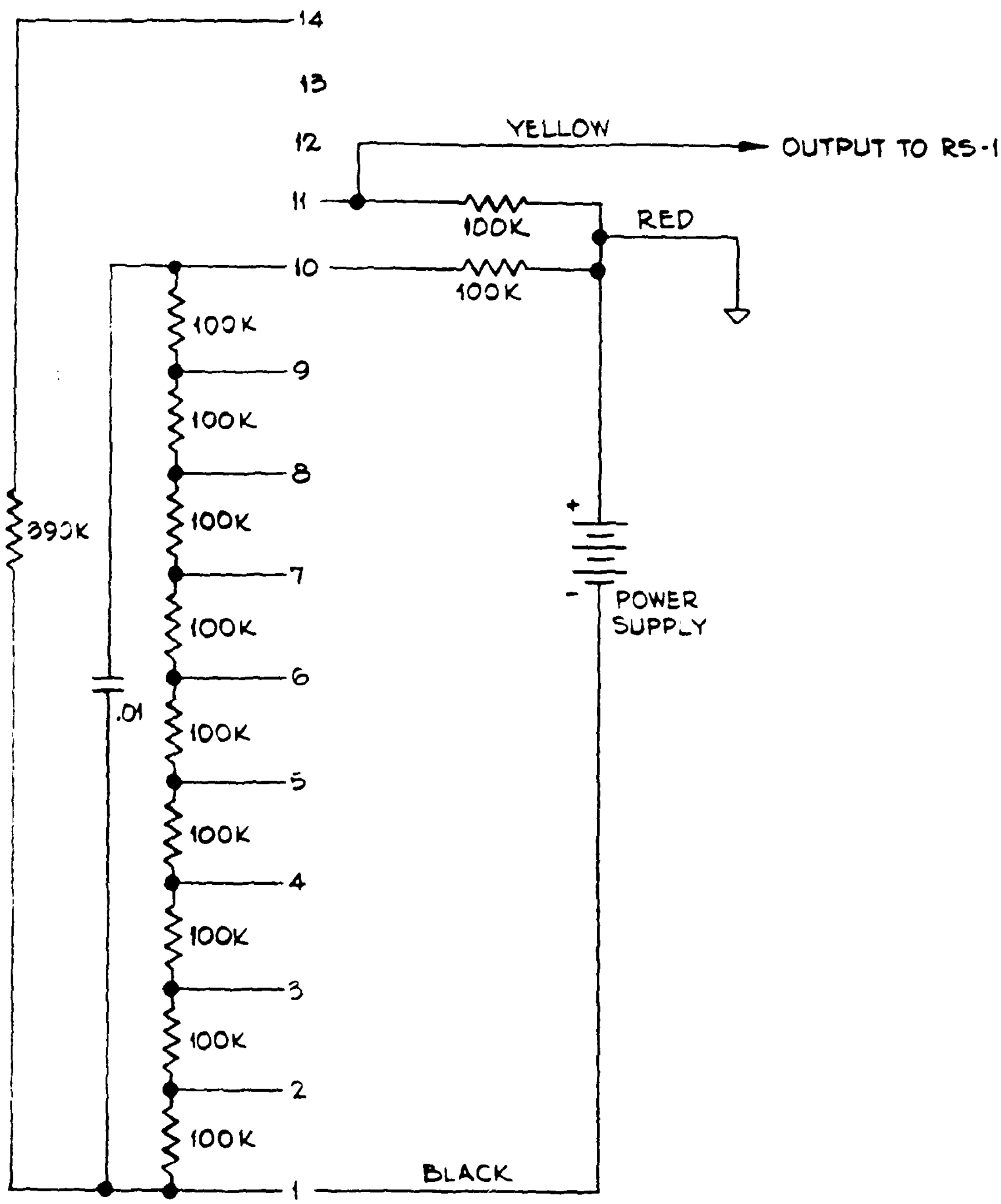

Figure 10 PMT Connections

The analog signal is fed to an analog to digital converter (A/D) in the RST (Figure 8). This device samples the input signal and digitizes it into an 8 bit byte (256 levels) at the element scan rate. Thus, as the scanned image modulates the scanning electron beam, digitized video data is developed in the RST. The data is then formatted as desired (black and white or gray level; binary or run length code) and passed to the computer memory via a direct memory access (DMA) device. Data is controlled by the DMA a word at a time where each word equal two bytes or 16 bits to a 9 track magnetic tape recorder (DEC TU-10)which records the digital data at a density of 800 bits per inch and a rate of 45 inches per second.

The recorded digital data is in the correct format required to drive the Cartographic EBR system in a raster recording mode. No further computer processing of the data is required before it can be used to control the electron beam recording of the digitized image. Therefore the image recorded on tape may be normally processed and displayed on the monitor or plotted on film (or both).

2.3.5 Software

Software control of an RST scan operation is not very different from a plot operation. Since parameters such as RLC, B&W, window width, etc. are used both in plot and scan modes of operation these parameters did not require any modifications.

The two sections of the RST plot software which were modified for scan operation are listed below:

1) The operator is asked if the current operation is a plot or scan operation. If "scan" is required a "scan flag" is set in the software and the scan bit in the RST command register is set.

2) Normal data flow is Input from Tape andoutput to RST. If scan flag is set the Input device is assigned to the RST and the output device is the Tape unit.

The above modifications to the original program are contained in the program listings given in Appendix B. The additional scan capability has been installed and is working in the current EBR system.

2.4 Details of Scanner Experiments

2.4.1 General

A number of experiments were conducted to investigate the feasibility of using the Electron Beam Recorder/Raster Scan Translator system as an Electron Beam Scanner. Initially, tests were performed using Kodak SO-214 35mm Scintillator film to demonstrate basic scanner test set-up functioning, scanner resolution and grey shade capability. Later tests involved coating images previously recorded on SO-219 35mm film samples with various scintillation coating materials and scanning these film samples in the EBR. Finally a test was conducted to determine the uniformity of light pickup by the PMT over a 5 inch by 8 inch scan area for large format scan capability.

In all image scanning tests, electron beam accelerating potential, scan ramp rate, number of scan lines and image area scanned were identical. EBR beam current and PMT output preamplifier gain and bandwidth limit were varied as light output and noise conditions required to produce recognizable image data. Test parameters are listed in Table I.

Table I Test Parameters

Electron Beam Acceleration Potential:	15 KV
Ramp Rate:	40 ms per 25 mm
Number of Scan Lines:	8000 per 43 mm
Beam Current:	5 na to 50 na
PMT Preamplifier Gain:	100 to 10K
PMT Preamplifier Bandwidth Limit:	10 KHz to 1 MHz

2.4.2 Flip Chart

In order to determine the feasibility of using scintillator film in an EBR system, it was decided to first record and scan a typical Air Force AAIPS Flip Chart thus providing some realistic and recognizable data for the initial investigation. The EBR was run under typical operating conditions for this test.

The test was conducted as follows:

1) Using the Symbol Vector Generator (SVG) in the Vector mode, a partial image of a Flip Chart was recorded on type SO-214 scintillator film. This data included various gray levels of information.

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2) The film was then processed using D8 developer for a period of 5 minutes and dried. A maximum density of 1.5 was obtained with this method.

3) The scanned data was computer processed and formatted by the RST using the Black and White binary mode and recorded on magnetic tape. The data was then played back in the Plot mode and displayed on a Tektronix type 4014-1 monitor in order to demonstrate that some recognizable data had indeed been recorded. This part of the experiment was successful as it showed that:

a) Scanned data could be displayed on a monitor.

b) The scanned data appeared to be geometrically correct as far as could be determined using the lower resolution display.

c) The scan circuitry was functioning properly.

d) Scan data could be immediately replotted with no additional computer processing.

e) The scan software program developed was correct.

f) The experimental set-up for scanning was satisfactory.

4) Following the display demonstration, the image was plotted on type SO-219 (5½ inch) film at 4.8X magnification with the EBR and processed into a visible image in the normal manner. As expected, only high density data was detected in the scan process since the Black and White mode was used, thus eliminating all gray levels below the maximum level. However, it did appear that all data of the proper (or highest) density was detected and recorded.

The results of this experiment are considered to be highly successful as they aptly demonstrate the feasibility of converting an EBR system into a combination scanner/plotter system. It is especially noteworthy, that this was accomplished with standard equipment and no state-of-the-art advances were required. Refinement of the scan set-up and equipment should greatly improve the overall system response and capability.

Figure 11 shows the original plot on SO-214 film and the resultant scanned data plotted on SO-219 film.

2.4.3 Resolution Target

In order to obtain some standard data which could be easily analyzed to aid in determining the basic capability of the scanning test set-up, a contact print of an Air Force resolution target was made using scintillator SO-219 film. This was accomplished simply by placing the target over the scintillator film and exposing it to room light for 2-3 seconds.

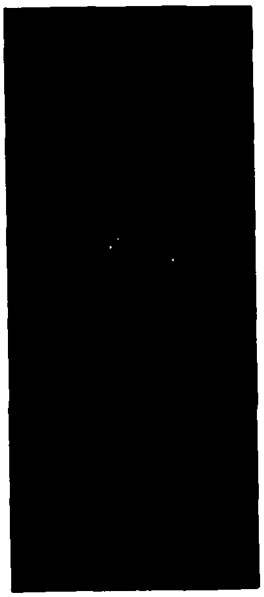
As in the previous experiment, the SO-214 film was scanned (using the RST) in the black and white mode and the digitized data recorded on magnetic tape. Again the data was plotted back and first displayed on the monitor to demonstrate that the film image had been scanned correctly. The image was then replotted at 4.8X magnification on 5½" SO-219 film and the results examined. It was found that with the EBR's 1/4 mil beam, lines as small as 1/2 mil had been resolved in the scan mode of operation. The limitation in resolution was attributed to the response time of the Tektronix amplifier used following the PMT to amplify the PMT signal. Use of an amplifier specifically designed to operate in this type of circuit will increase the overall system response resulting in higher scanning resolution.

Figure 12 shows the original contact print on SO-214 film and the resulting scan/plot mode on SO-219 film.

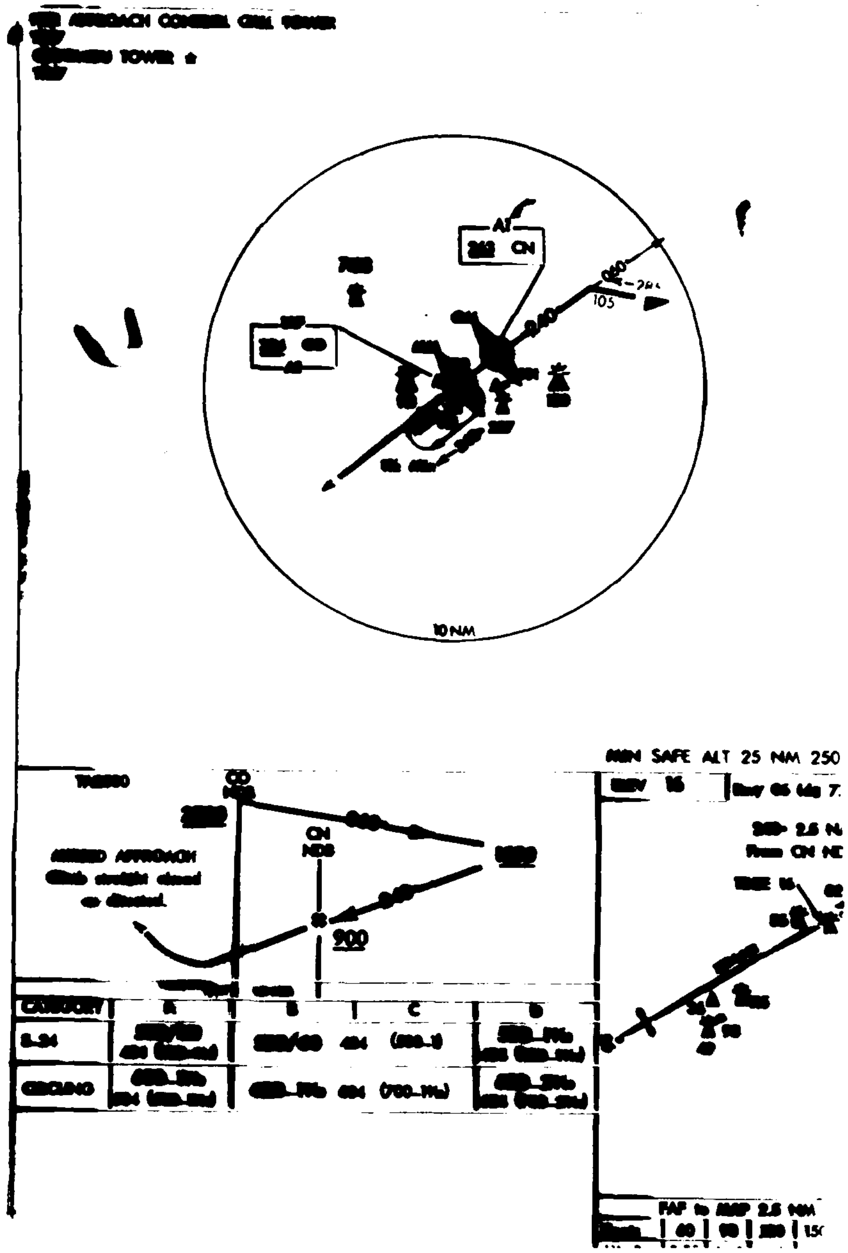
2.4.4 Grey Shades

A 16 step grey scale stairstep pattern was recorded on SO-214 Scintillator film using the EBR as a plotter and the Raster Scan Translator Internal Calibration pattern generator as the EBR input. Video gamma, video gain and beam current were adjusted in the EBR to produce 15 visible grey shade steps on the scintillator film.

After film processing, the scintillator film image was placed back into the EBR and scanned, under Raster Scan Translator control, in Binary/Grey Scan mode. Scan data was output to magnetic tape. During the scanning operation, EBR beam current was set high (30 to 50 na) and the PMT output preamplifier gain was turned down to 100 to increase the signal to noise ration while

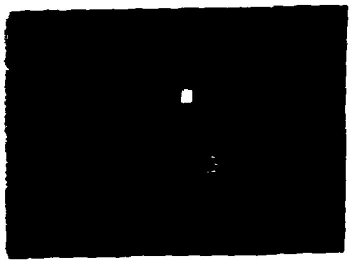


Original Image
Scanned by
E-Beam Scanner

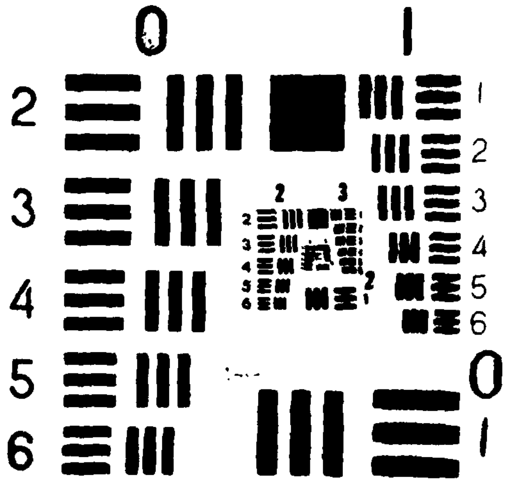


EBR Recording of Scanned Data (4.8X)

Figure 11 Flip Chart Experiment



Original Image Scanned
by E-Beam Scanner



EBR Recording of Scanned Data (4.8X)

Figure 12 Resolution Experiment

providing the proper signal level for the RST input. The preamplifier bandwidth was set at 1 MHz.

The scan data recorded on magnetic tape was then recorded on 5 1/2" wide SO-219 film in the EBR ar a 4.8X magnification. Video gamma, video gain and beam current were adjusted in the EBR to produce 15 visible grey shade steps on the SO-219 film.

Figure 13 shows the original grey shade test pattern on SO-214 scanned with the EBR and the resultant recording produced on SO-219.

2.4.5 Luminescent Coatings

A number of simple experiments were conducted with luminescent and scintillator materials coated on images previously recorded with the EBR or other photographic means. The coated images were then scanned with the E-Beam scanner under Raster Scan Translator control in binary mode.

As in the previous experiments the scanned data was recorded on magnetic tape. The magnetic tape was used as an input to the EBR to replot the data on 5½" wide SO-219 film at 4.8X magnification. A typical example of the original image scanned and the resultant replot from the scanned data is shown in Figure 14.

Some of the luminescent coatings tested were Kodak PPO and POPOP liquid scintillators in aqueons and toluene solutions and various florescent enamels. The results of even this simple investigation clearly indicates that luminescent coatings (i.e. scintillators) which are suitable for EBR scanning can readily be applied to any photograph image on film.

To establish proper scintillator coating techniques as practical operational procedures for the electron beam scanning process requires further investigation and materials development which were beyond the scope of this program.

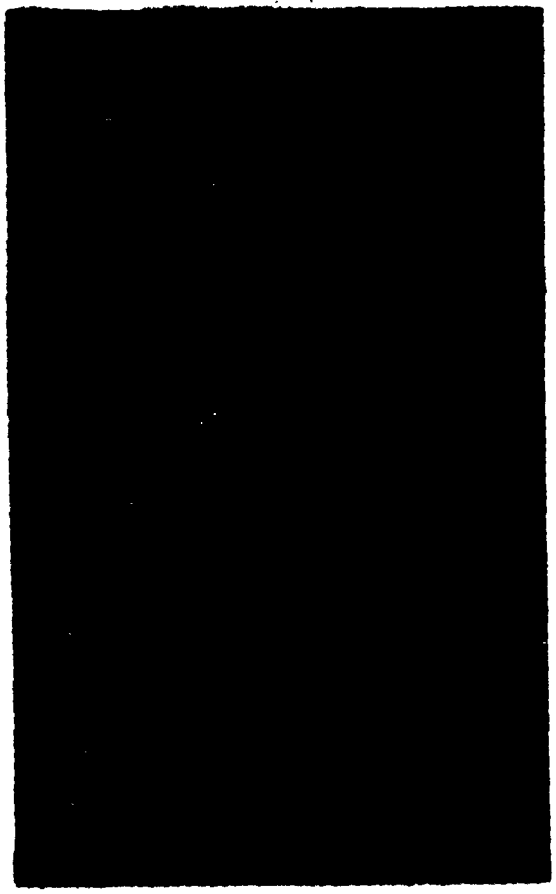
2.4.6 Large Format Electron Beam Scanner-Light Pickup Considerations

All scanner tests previously discussed in this report were conducted with 35mm film samples over a 25mm x 43mm scan area. In order to gain insight into the feasibility of scanning larger format areas with the Electron Beam Scanner, a test was conducted to determine the variation in light pickup from a 5 inch by 8 inch scan area when only one PMT is used.

Original Image Scanned with E-Beam Scanner

Density

1.92
1.83
1.75
1.67
1.58
1.43
1.19
.91
.70
.55
.45
.39
.34
.33
.31



EBR Recording of Scanned Data

Figure 13 Gray Shade Experiment

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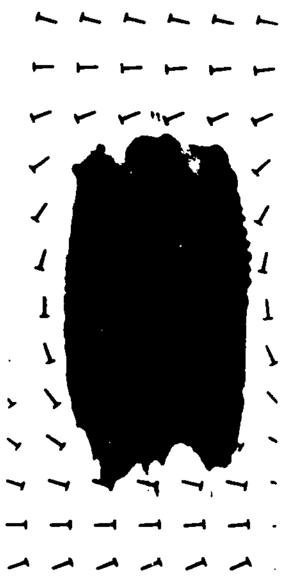
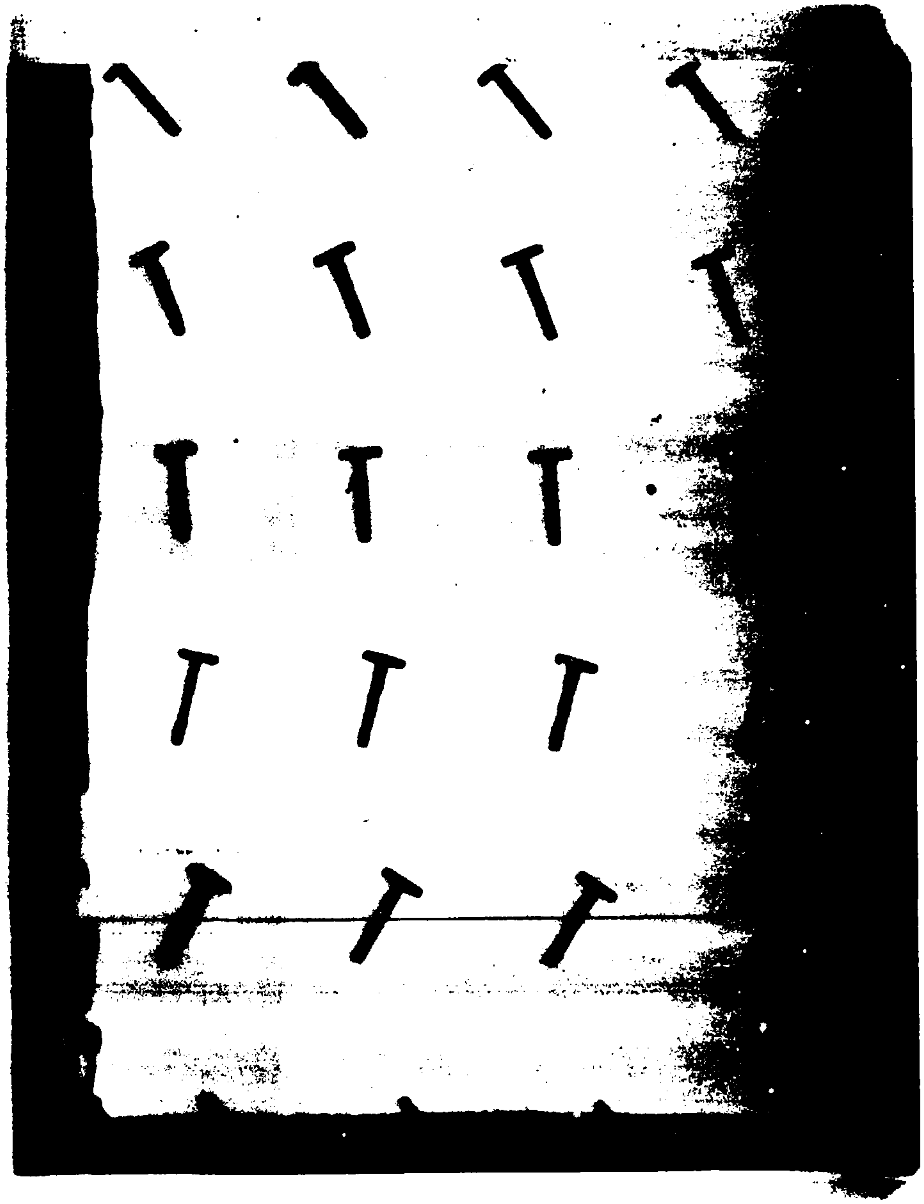


Original Image
Scanned By
E-Beam Scanner



EBR Recording of Scanned Data (4.8X)

Figure 14 Luminescent Coating Experiment

The PMT was mounted, as in previous tests, in the center of the format, 9 inches from the surface of the image scan plane. A 5 inch by 8 inch phosphor-coated glass plate was installed in the EBR. The center of the phosphor plate was scanned and the output of the PMT was adjusted for a convenient signal level. The corners and edges of the phosphor plate were then scanned and the difference in light pickup (PMT signal) between these areas and the center of the format was measured. Assuming that the light emitted from the phosphor plate was uniform across the entire 5 inch by 8 inch area, it was determined that approximately 1/2 to 2/3 of the available light was picked up by the PMT when the corners and edges of the phosphor plate were scanned. It should also be noted that the film vacuum chamber in which this test was conducted did not have removable film transport drive shafts and these provided some obstruction to the light emitted along the left and right edges of the phosphor plate.

It appears reasonable to assume that for line work or graphic, adequate signal can be obtained from a 5" x 8" surface with a single PMT. For scanning large format continuous tone imagery it will be necessary to either improve the uniformity of the light collection system or to provide some electronic intensity compensation.

3.0 Conclusions and Recommendations

1. The results of this program clearly demonstrate that an electron beam scanner mode of operation can be added to a Cartographic EBR System which allows cartographic line and gray shade data on film to be rapidly digitized using a high resolution raster scanning electron beam.

2. Special Scintillator film as well as conventional EBR film coated with luminescent materials, may be used for electron beam scanner applications.

3. The analog signal processor circuitry developed for encoding data and imagery scanned by the electron beam and the PDP 11 minicomputer controller hardware and software have been successfully tested. This circuitry and associated software could be added to the Raster Scan Translator in the Pre-production Model Cartographic EBR System installed at the Hydrographic/Topographic Center for future scanner applications.

4. A number of experiments were successfully conducted showing the feasibility of coating images on conventional film with a luminescent coating which could be used with the electron beam scanner. Further investigations of luminescent materials and coating processes should be conducted to develop a luminescent film coating processor which could be used in an operational environment.

5. Experiments conducted by contact printing graphics or gray shade imagery on a standard electron sensitive scintillator film and then using the prints in the electron beam scanner were very successful. This technique could be adapted immediately for some scanner applications.

6. Large size cartographic color separations could be imaged with a camera onto a roll of electron sensitive scintillator film, the roll of film would then be processed and placed in the EBR for scanning. In concept, this is just the reverse of recording on microfilm and then enlarging to final size.

Although the microfilming would be an extra step, the advantage would be improved scanning throughput.

7. A photomultiplier readout station for large formats (i.e. 5" x 8") should be developed for the Cartographic EBR. This would provide the EBR with a capability of scanning a matrix of up to 20,000 x 32,000 elements.

8. The Electron beam Scanner (EBS) capability should be added to the Pre-Production Model Cartographic EBR System at the Hydrographic/Topographic Center.

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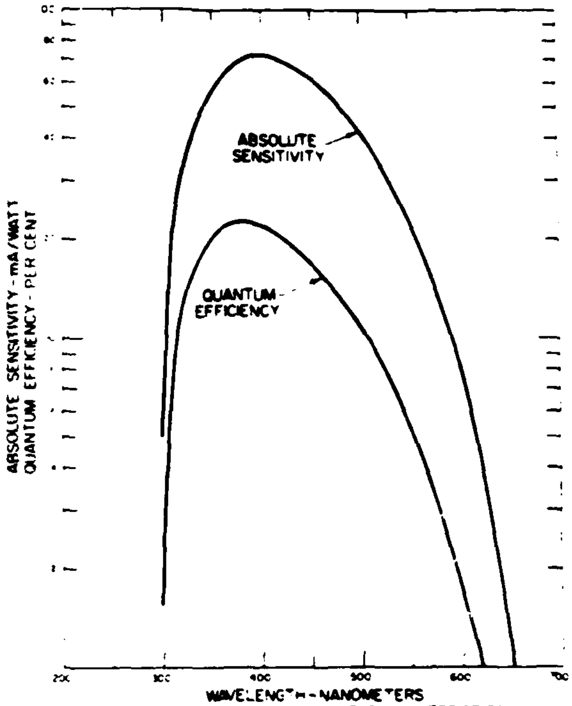
Appendix A

Specification Sheet for Photomultiplier Tube

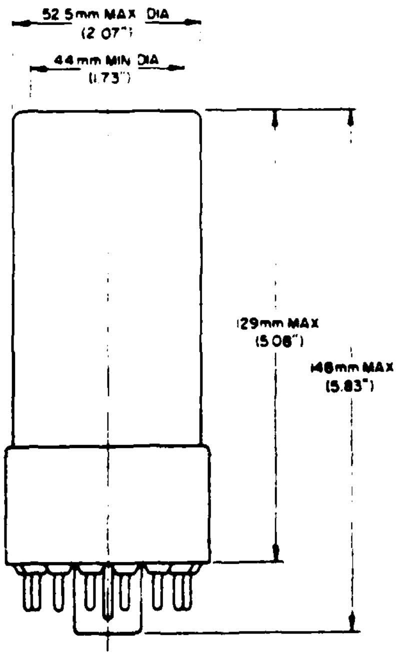
52B01 PHOTOMULTIPLIER TUBE

The SRC 52B01 is a 2" diameter 10 stage end-on photomultiplier designed for scintillation counting and other applications where high quantum efficiency, low dark current, good collection efficiency and gain stability are of paramount importance.

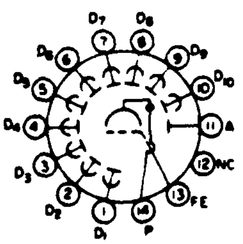


TYPICAL SPECTRAL RESPONSE CHARACTERISTICS

FIGURE 1



BASING DIAGRAM
Bottom View



D – DYNODE
A – ANODE
P – PHOTOCATHODE
FE – FOCUS ELECTRODE
NC – NO CONNECTION

GENERAL DATA

Photocathode: Semi-transparent Bialkali (Cs-K-Sb)	
Spectral response	See Figure 1
Wavelength of maximum response	400 ± 50 nm
Minimum diameter	44 mm
Window shape	plano-plano, circular
Window index of refraction @ 436 nm	1.523
Evaporator	Single Point Source
Dynodes	Copper-beryllium, venetian-blind
Capacitance (anode to all electrodes)	8 pF
Mechanical dimensions	See Figure 2
Base	Medium-shell Diheptal 14-pin (JEDEC No. B14-38)
Socket	Cinch No. 3M14, or equivalent
Operating position	Any
Weight (approx.)	200 grams

ELECTRICAL RATINGS

	Minimum	Typical	Maximum	
Cathode to dynode No. 1 voltage			500	VDC
Cathode to anode voltage			2250	VDC
Anode to dynode No. 10 voltage			300	VDC
Voltage between consecutive dynodes			300	VDC
Ambient storage temperature	−100		+85	°C
Anode current, averaged over 30 sec.			0.5	mA
Anode dissipation			1	W
Cathode current			0.3	μA
Cathode luminous sensitivity:[1]				
With 2854° K tungsten source		60		μA/L
With blue light source[2]	7	9		μA/L(B)
Quantum efficiency @ 400 nm		22		%
Cathode radiant[3] sensitivity @ 400 nm		0.071		A/W
Anode luminous sensitivity @ 1500 VDC overall:				
With 2854° K tungsten source of 1×10^{-6} L	10	27		A/L
With blue light source[4]	1.5	4		A/L(B)
Anode radiant[5] sensitivity @ 400 nm and 1500 VDC		3.2×10^{4}		A/W
Current amplification @ 1500 VDC		4.5×10^{5}		
Anode dark current[6] @ 22° C		5×10^{-10}	3×10^{-9}	A
Pulse height resolution		7.5		%

(1) With 300 VDC between cathode and all other elements connected as anode

(2) This measurement is made with a blue filter (Corning C.S. No. 5-58 ½ stock thickness) interposed between a calibrated 2854° K tungsten light source and the photocathode. The (B) appearing in the units [μA/L(B)] signifies that the measurement is made with the blue filter in place.

(3) Calculated from typical cathode luminous sensitivity using conversion factor of 1190 lumens per watt.

(4) This measurement is made with a blue filter (Corning C.S. No. 5-58, ½ stock thickness) interposed between a 2854° K tungsten light source of 1×10^{-6} lumen and the photocathode. The (B) appearing in the units [A/L(B)] signifies that the measurement is made with the blue filter in place.

(5) Calculated from typical anode luminous sensitivity using conversion factor of 1190 lumens per watt.

(6) Measured at that supply voltage which gives an anode current of 20 microamperes with the cathode illuminated by *blue light* as follows:

1. The white light level from a 2854° K tungsten source is adjusted to give 10 micro lumens at the photocathode.
2. A blue filter (Corning C.S. No. 5-58, ½ stock thickness) is interposed between the light source and the photocathode.

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TELEPHONE 203-366-3861

END

DATE